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JEM-EUSO EXPERIMENT FOR EXTREME ENERGY COSMIC RAY OBSERVATION

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The planned JEM-EUSO (Extreme Universe Space Observatory onboard the ISS Japanese Experimental Module) will measure the energy spectra of cosmic rays up to the range of 10^{21} eV and will search for direction to their sources. It will observe the extensive air showers generated in the atmosphere by high energy cosmic ray primary particle from the space. The instantaneous aperture of the telescope will exceed by one order the aperture of the largest ground based detectors. JEM-EUSO apparatus is a large telescope with a diameter of 2.5 m with fast UV camera. Slovakia is responsible for the determination of the UV background, which influences the operational efficiency of the experiment and for the analysis of fake trigger events.

1 Extreme Universe Research

The origin and existence of the extreme energy cosmic rays (EECRs) and the physical mechanism of their acceleration to very high energies are an open puzzle in contemporary astroparticle physics. The highest observed cosmic rays energy is about 3×10^{20} eV, which exceeds by 8 orders the CERN LHC energy scale.

Such extremely powerful sources capable of accelerating cosmic rays up to EECRs energies have to be confined within a limited range of distances set by the Greisen-Zatsepin-Kuzmin cutoff of 6×10^{19} eV [1], which is caused by interactions of cosmic rays with the cosmic microwave background. Possible indications of sources or excesses in arrival direction distribution of EECRs have been claimed by several ground based experiments [2], [3], [4], [5] implying that the sources have to be up to several tens *Mpc* far. Possible EECRs sources are supernovae, pulsars, gamma ray bursts, active galactic nuclei and recent collisions of radiogalaxies. However, most of these candidates are incapable of accelerating particles beyond 10^{20} eV by any known acceleration mechanism.

To identify the sources of EECRs, the measurements of the energy spectrum and arrival directions of such particles are needed. Although low energy charged particles are bent by magnetic field in intergalactic and galactic space so that the directional information of their origin is lost, the highest energy particles are barely bent, thus retaining the information of the direction to the origin. The EECRs flux is exceptionally low, of the order of $1 \text{ particle}/\text{km}^2/\text{sr}/\text{century}$ at energies above Greisen-Zatsepin-Kuzmin energy. At the high end of the spectrum, $E > 10^{20}$ eV, it reduces even to about $1 \text{ particle}/\text{km}^2/\text{sr}/\text{millenium}$ (Figure 1). This challenging extreme energy region is the scope of the Extreme Universe Space

Observatory (EUSO) attached to the Japanese Experiment Module (JEM) on board the International Space Station (ISS) [6].

The size of the observational area is a critical factor for detecting the rare EECRs events. Currently, the leading observatories of EECRs are ground based, that cover large areas with particle detectors overlooked by fluorescence telescopes. The largest one is the Pierre Auger Observatory in Argentina with a surface detector array covering 3000 km^2 which accumulates annually about $6 \times 10^3 \text{ km}^2 \text{ sr yr}$ of exposure [7]. The more recently constructed Telescope Array (TA) covers 700 km^2 which should accumulate annually $1.4 \times 10^3 \text{ km}^2 \text{ sr yr}$ of exposure. Although extremely large, ground based observatories have nearly reached the maximum extent possible on earth. Space observatory makes a giant leap in the area size observed (Figure 2). JEM-EUSO mission explores the origin EECRs and explores the limits of the fundamental physics, through the observations of their arrival directions and energies. An additional relevant advantage comes from the orbit, as JEM-EUSO will monitor with a rather uniform exposure both hemispheres thus minimizing the systematic uncertainties that strongly affect any comparison between different observatories exploring, from ground, different hemispheres.

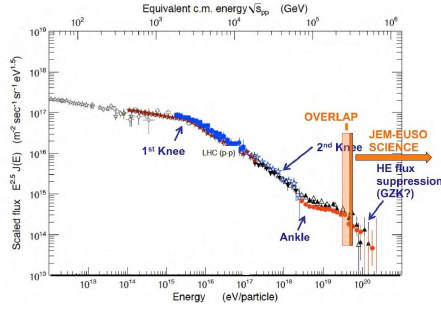


Figure 1. Scaled energy spectrum of cosmic rays

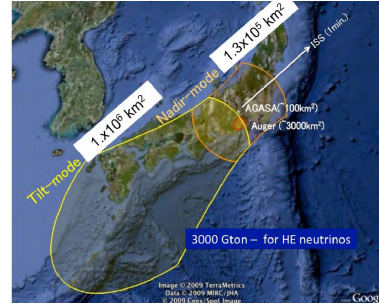


Figure 2. The instantaneous aperture observed by the JEM-EUSO telescope compared with some ground based experiments

2 JEM-EUSO Experiment

The proposal of the JEM-EUSO mission [8], [6], [9], [10] is an common project between the space agencies JAXA, NASA, ESA, Roskosmos and 13 collaborating countries (77 institutions, over 250 researchers). The leading country is Japan, which provides the basic infrastructure including a vehicle HII-B, a spaceship HTV and the position for detector emplacement onboard the ISS Japanese Experimental Module Kibo. It will operate minimum 3 years with starting date of 2017.

This innovative space mission will use the Earth's atmosphere as a detector of cosmic ray showers. JEM-EUSO exploits the fluorescence light that is emitted during the development of the Extensive Air Shower (EAS) initiated by a primary

cosmic ray particle in the atmosphere to estimate the energy and arrival direction of EECRs. JEM-EUSO will measure the energy spectra of cosmic rays up to 10^{21} eV and will search for direction to their sources. By observing from space the fluorescence and Cherenkov light emitted by EAS, the species, energy and direction of the primary is well determined.

Figure 3 illustrates the EECRs observation principle in the JEM-EUSO mission. On the orbit of altitude 400 km the JEM-EUSO telescope detects fluorescence and Cherenkov light from the EAS. The former directly heads to the telescope. The latter is observed either because of scattering in the atmosphere or because of diffuse reflection from the surface or the cloud on which the Cherenkov beam impacts. An incoming 10^{20} eV EECR produces an order of 10^{11} particles at shower maximum during the EAS development. The secondary particles are still relativistic and the charged particles, most dominantly electrons, excite the nitrogen molecules to emit UV fluorescence light of characteristic lines in the wavelength range of $300 - 430 \text{ nm}$. The total yield of $4 - 5 \text{ photons/m/electron}$ [12], [13] is almost independent of the altitude. Along the development of a 10^{20} eV EECR shower order of 10^{15} photons are isotropically emitted. Seen from 400 km distance, the solid angle of the telescope with a few m^2 aperture is about 10^{11} sr . In the clear atmospheric condition, therefore, it results in few thousands photons reaching the pupil of the telescope. JEM-EUSO is designed to record not only the number of photons but also their direction and arrival time.

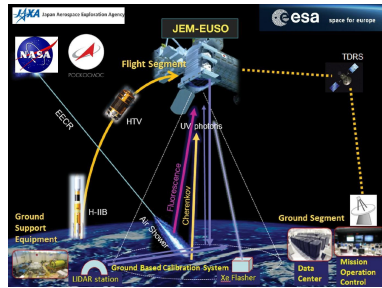


Figure 3. JEM-EUSO overview and principle of operation

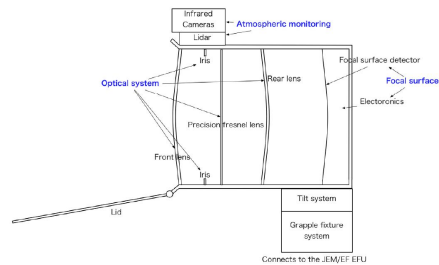


Figure 4. Telescope

Technically JEM-EUSO is a large telescope with a diameter 2.5 m with fast UV camera. The telescope [14] is an extremely fast (camera takes 400000 frames/s), highly pixelized (more than 300000 pixels) instrument. These allow to record cascade in angle and time. Camera will record video clips of fast moving UV tracks sensing the fluorescence light representing the temporal development of EAS.

The telescope (Figure 4) mainly consists of four parts: the photon collecting optics [15], the focal surface (FS) detector [16], the electronics [17] and the mechanical structure [18]. Since the development of the EAS and the intensity of the observed light depend on the transmittance of the atmosphere, the cloud coverage and the height of cloud-top, JEM-EUSO is equipped with an atmospheric monitoring (AM)

system [19]. To estimate as precisely as possible the atmospheric conditions and the effective observation aperture with high accuracy, AM system will consist of an infrared (IR) camera, a LIDAR system and may benefit the use of UV data acquired continuously by the telescope itself.

3 Our Contribution

In Slovakia the Institute of Experimental Physics is participating in JEM-EUSO experiment preparation. We are responsible for several tasks. The main are:

- The estimation of the UV background on the night side of the Earth Sources of the background
- The determination of the JEM-EUSO operational efficiency fraction of time when monitoring UV compared to full time on orbit. Above mentioned UV background sources together with ISS operation schedule had to be taken into account in the model of JEM-EUSO operational efficiency
- The fake trigger event simulations and analysis

The main sources of the UV background are the reflections from sky (Moon, stars, planets), man made lights, lightnings, airglow, aurora, meteorites. Most of them are yet included into the simulations.

The operational efficiency is a fraction of the time when monitoring UV compared to full time on orbit. Above discussed contributions to the UV background together with ISS operation schedule had to be taken into account in the model of JEM-EUSO operational efficiency.

The most relevant background component affecting the observational duty cycle is the effect of the Moon. We estimated the moonlight component from the phase of the Moon and its apparent position as seen from the ISS. In our approach the ISS trajectory provided by NASA SSCweb was traced with 1-min time steps and the moonlight at the top of the atmosphere was estimated according to [20]. For every position of the ISS in the period from 2005 till 2007 the zenith angle of the Sun, and that of the Moon as well as the moon phase angle were calculated. The contribution to background level due to reflected moonlight was evaluated in the way described in the following, modified from [21].

The summary of all effects taken into account in evaluation of operational efficiency up to now is presented in Figure 5.

The last issue among our responsibilities in JEM-EUSO experiment preparation is the simulation and following analysis of the fake trigger events. The goal of the trigger system is to detect the occurrence of scientifically valuable signal from the EECRs events among very huge background noise detected by JEM-EUSO [22]. Its expected rate is up to $10^{11} Hz$, see Figure 6. The UV background registered by JEM-EUSO is randomly distributed with Poissonian character. We study, if these random processes produce fake pattern, which could be mistakenly interpreted as EECRs events. We are simulating huge amount of measurements on one model PDM (Photo Detector Module) with only detector noise. In the simulation code two main trigger levels are implemented and consequently such filtered output is

I_{Allowed} [ph/(m ² ns sr)]	$I_{\text{SUN}} >$ 109.18°	I_{MOON} only [%]	Cities only [%]	$I_{\text{SUN}} +$ I_{MOON} [%]	$I_{\text{SUN}} + I_{\text{BG}}$ + I_{MOON} [%]	$I_{\text{SUN}} + I_{\text{BG}}$ + $I_{\text{MOON}} +$ Cities [%]
1		50.00	90.14	17.83	0.00	0.00
10		50.11	90.14	17.85	0.00	0.00
100		51.14	90.18	18.14	0.00	0.00
300		53.45	90.18	18.72	0.00	0.00
500		55.92	90.26	19.25	0.00	0.00
1000	34.84	62.06	90.26	20.41	19.25	17.46
1500		68.08	91.06	21.43	20.41	18.51
5000		89.73	95.97	26.73	26.07	23.61
10000		97.85	98.81	32.69	32.20	29.15
15000		99.99	100.00	34.83	34.80	31.55
30000		100.00	100.00	34.84	34.84	31.58

Figure 5. Summary of all calculated effects contributing to operational efficiency

going to be analysed [23]. To distinguish between such simulated fake events and real EECRSs events and find the probability of registration fake event we are applying and developing pattern recognition methods, especially Hough transform method [24].

Level	Rate of signals/triggers at PDM level	Rate of signals/triggers at FS level
Photon trigger	$\sim 9.2 \times 10^8$ Hz	$\sim 1.4 \times 10^{11}$ Hz
Counting trigger	$\sim 7.1 \times 10^5$ Hz	$\sim 1.1 \times 10^8$ Hz
Persistency trigger	~ 7 Hz	$\sim 10^3$ Hz
2 nd level trigger (PDM cluster)	$\sim 6.7 \times 10^{-4}$ Hz	~ 0.1 Hz
Expected rate of cosmic ray events	$\sim 6.7 \times 10^{-6}$ Hz	$\sim 10^{-3}$ Hz

Figure 6. The description of the rate reduction on different trigger levels

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